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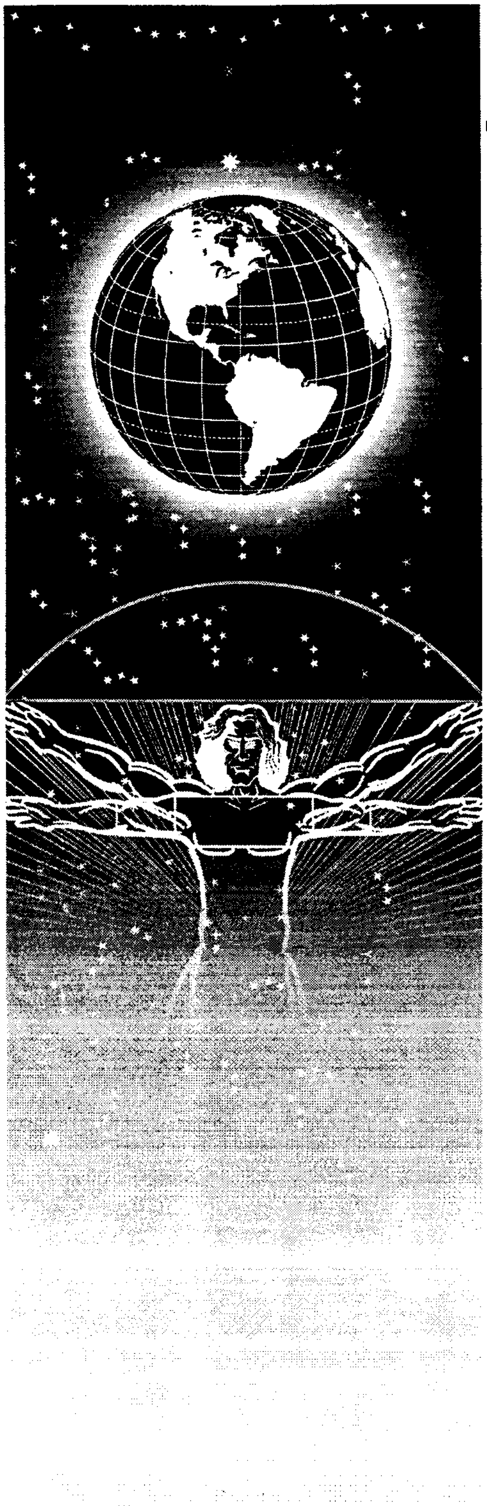

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Advanced Distributed Simulation and the Fog of Simulation: Lessons Learned from the Cockpit

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March 1997

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The Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) has participated in a number of Advanced Distributed Simulation (ADS) exercises. These exercises included Warbreaker, the Synthetic Theater of War-Europe (STOW-E), Multi-Service Distributed Training Testbed (MDT2), and Warfighter 95. Each of these exercises successfully linked large numbers of simulators and enhanced the technical capabilities of ADS. These exercises also suggested that ADS offers unique training opportunities for warriors, battle staffs, and commanders. Unfortunately, these training opportunities were not demonstrated to the same degree as the technology. We believe part of the reason for the failure to fully demonstrate the training potential of ADS stems from problems in adequately defining requirements, appropriately scoping exercises, thoroughly testing simulations, and maintaining real-time exercise control. This paper describes the typical problems we encountered as a node providing virtual simulations of tactical aircraft in support of larger ADS exercises while at the same time trying to provide combat mission training for the pilots flying those simulators. In addition, this paper provides recommendations that we believe will enhance the training value of ADS exercises for participants in simulated weapons systems.

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PREFACE

This paper describes the participation of Armstrong Laboratory, Aircrew Training Research Division (AL/HRA) in a number of Advanced Distributed Simulation (ADS) exercises which successfully linked large numbers of simulators. The purpose of the paper is to describe some of the recurring problems that were seen in the ADS exercises. Recommendations are provided that will enhance the training value of ADS exercises for participants in simulated weapons systems.

This work is being reported under Work Unit 1123-B2-15, Synthetic Environments for Air Warrior Training Research. Dr Herbert H. Bell was the principal investigator. This paper documents a presentation made to the American Institute of Aeronautics and Astronautics (AIAA) Flight Simulation Conference which was held 29-31 July 1996 in San Diego CA. This presentation was also published in the conference proceedings, AIAA-96-3539-CP, pp 573-578.

ADVANCED DISTRIBUTED SIMULATION AND THE FOG-OF-SIMULATION: LESSONS LEARNED FROM THE COCKPIT

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Abstract

The Armstrong Laboratory's Aircrew Training Research Division (AL/HRA) has participated in a number of Advanced Distributed Simulation (ADS) exercises. These exercises included Warbreaker, the Synthetic Theater of War-Europe (STOW-E), Multi-Service Distributed Training Testbed (MDT2), and Warfighter 95. Each of these exercises successfully linked large numbers of simulators and enhanced the technical capabilities of ADS. These exercises also suggested that ADS offers unique training opportunities for warriors, battle staffs, and commanders. Unfortunately, these training opportunities were not demonstrated to the same degree as the technology. We believe part of the reason for the failure to fully demonstrate the training potential of ADS stems from problems in adequately defining requirements, appropriately scoping exercises, thoroughly testing simulations, and maintaining real-time exercise control. This paper describes the typical problems we encountered as a node providing virtual simulations of tactical aircraft in support of larger ADS exercises while at the same time trying to provide combat mission training for the pilots flying those simulators. In addition, this paper provides recommendations that we believe will enhance the training value of ADS exercises for participants in simulated weapons systems.

Introduction

Advanced Distributed Simulation (ADS) is viewed as a technology that will enable us to design better systems, develop better tactics, and train better warfighters. Since its beginnings in the Defense Advanced Research Projects Agency's (DARPA's) Simulator Networking project, ADS has shown tremendous technological advances. An Institute of Electrical and Electronics Engineers (IEEE) standard exists for Distributed Interactive Simulation (DIS)[1] and extensive simulation networks capable of creating complex synthetic battlefields have been demonstrated. ADS is clearly the dominant theme in today's simulation and training communities.

We have participated in several ADS exercises including Warbreaker, Synthetic Theater of War-Europe (STOW-E), Multi-Service Distributed Training Testbed (MDT2), and Warfighter 95. One of our roles in each of these exercises was to provide high-fidelity tactical aircraft simulators flown by Air Force pilots. These exercises allowed us to participate in distributed simulation environments with large numbers of other participants and simulations. Each of these exercises was a technological success. Yet each exercise was also an expensive and often frustrating experience for us and our pilots. The primary reasons for this were that the techniques and procedures necessary to effectively and efficiently design, implement, and conduct ADS exercises were, and are still, very immature.

The purpose of this paper is to describe the recurring problems we saw in these ADS exercises as a small virtual simulation node. In addition, we will offer some recommendations that we believe will reduce the effects of some of these problems and enhance the training value of ADS exercises.

Exercise Planning

Requirements Definition

The biggest problem we have encountered in distributed simulation exercises is the absence of well-defined objectives for the human participants. To date, the majority of ADS exercises have focused on creating technologically complex synthetic environments. As a result of this technology emphasis, exercise objectives have typically focused on correcting the technical shortfalls identified in previous exercises and adding new capabilities. Therefore, the objectives tend to emphasize the number of participants, the addition of new simulators, the simulation of new phenomena, and associated improvements in computer and communication technology. Such technological advances are certainly necessary if ADS is to reach its full potential. Unfortunately, in many recent ADS exercises, it often seems as if the human participants in the simulators are merely aids needed to demonstrate the operation of the technology.

We believe the first step in improving the value of ADS exercises is to identify the training audience and the associated training objectives. Exercise planners, training professionals, and technologists must work together to define the training or mission objectives for the individual warfighters and scope the exercise to meet these objectives. Failure to develop such detailed objectives means it is difficult to define the federation of simulators necessary for the exercise. In addition, it is difficult to determine how those simulators should interact with one another and to specify when those interactions should occur. Hopefully, some of these deficiencies will be eliminated as future ADS exercises adopt the Defense Modeling and Simulation Office's (DMSO's) High Level Architecture (HLA). HLA requires formal definitions of all simulation interactions as part of the federation development process.[2]

Once the training objectives and simulator federation have been clearly identified, the exercise planners, trainers, and technical staffs can begin the iterative process of designing an ADS-based exercise. During this phase, the design team must ensure that the simulation scenario is consistent with the training objectives. Once the draft scenario exists, the design team must explicitly review individual simulator capabilities. During this review, weapon system operators (e.g., pilots) must describe the stimuli and responses necessary for them to perform their assigned mission within the draft scenario. The technical experts familiar with the simulations can then describe how these events will appear in the virtual world. Our experience has repeatedly shown that neither DIS protocols nor individual simulators are capable of faithfully reproducing all aspects of the battlefield. In addition, different simulators may reproduce the same aspect of the battlefield at different levels of fidelity. As a result of these discrepancies, changes to individual simulators, DIS protocols, exercise scenarios, or training objectives are typically required. These changes are necessary to eliminate technically impossible events and to identify workarounds to enable other events to appropriately occur. Usually, this review and modification process requires several iterations.

As part of defining the scenario and simulator requirements, the design team must also specify the communications requirements for the exercise. Typically, communication requirements involve both simulation data and voice communications. Simulation data includes the exchange of platform and weapons state information among the participating entities. Voice communication usually includes tactical, exercise control, and technical/simulation troubleshooting nets. In addition, both voice and data communication may be required to support mission planning and after action reviews.

Appropriate Scoping of Exercises

A second problem with distributed simulation exercises, which is related to poor requirements definition, is improperly scoping the size of the exercise. Conventional wisdom seems to be the more entities you can put on the network, the more realistic the exercise. However, "more" is not necessarily "better" when it comes to creating synthetic environments. Large ADS exercises demand large resource commitments during both the development and conduct of the exercise. A large number of entities necessitates an extensive network bandwidth, which can be very costly. Also, the computers used to process the network traffic can become bogged down trying to meet real-time processing demands. In exercises like STOW-E, we have seen network interface units and plan-view displays become so overloaded during peak periods of traffic that they are barely useful. In addition, although the constructive simulations may be able to computationally handle the large number of entities used in exercises such as STOW-E, many virtual simulators cannot realistically process or display such large numbers of entities. Consequently, even though large numbers of entities are broadcast across the network, many virtual simulation nodes can realistically process and display only a tiny subset of those entities. Because these problems can have a negative impact on training, the size of the exercise should be limited to "just enough" entities to make the scenario realistic enough to meet the training objectives

In addition, large ADS exercises require extensive commitments of manpower and facilities to support both exercise development and execution. Most ADS exercises rely on existing legacy systems to provide the weapon system simulators. Since these legacy simulators are already fielded to support other requirements, ADS exercises must compete for personnel and time. This means either extending the period of simulator operation and increasing the number of personnel or reducing support to other programs.

Thorough Testing

Another obstacle to successfully accomplish training in distributed simulation is insufficient testing. Today, most distributed exercises use DIS protocols to allow communication among disparate simulation devices. It is up to each site to implement these protocols correctly; our experience has shown that this is not always done. For example, we recently participated in an ADS exercise in which several sites had major DIS discrepancies. These discrepancies included incorrect versions of the DIS protocols, incorrect entity identifications, incorrect dead reckoning, incorrect timestamping, and errors with PDU fields.

Noncompliance by one site impacts all other sites. At the very least, noncompliance wastes computer resources because each site must process bad data, and, at the worst, noncompliant data causes simulation devices and simulation nodes to "crash." The only way to avoid these problems is to have thorough DIS-compliance testing. During this testing, engineers using the correct DIS tools must analyze the data transmitted from each simulator to determine DIS compliance. Discrepancies must be reported to both the individual sites and to the exercise director. Once the various systems are compliant, the system configuration should be frozen until the completion of the exercise. Unfortunately, this rarely occurs. Typically, due to schedule pressures or last-minute additions of some new capability, testing is incomplete, and a mammoth engineering effort is needed just prior to the start of the exercise to pull everything together.

The first step in the testing process should be for the test director to clearly specify all the DIS Protocol Data Units (PDUs) necessary to exchange information between the sites. The specification must list the PDUs for each site and thoroughly describe any experimental PDUs that will be used during the exercise. These should be clearly documented and distributed to all sites to avoid any possible miscommunication. Armstrong Laboratory (AL/HRA) recently participated in an exercise where a requirement for an Identification Friend or Foe (IFF) PDU existed, but because no one created a list of which PDUs each site needed to support, we were unaware of the requirement. Late in testing, we noticed our F-16 simulators were being shot down by friendly Patriot missiles because they were expecting the F-16s to broadcast certain IFF codes. This problem occurred too late for us to implement the IFF PDUs, and during the exercise the F-16 pilots had to alter flight paths to avoid the Patriots. This "sim-ism" would have been avoided if the DIS PDU support requirements had been explicitly defined.

Once the required PDUs have been defined, each participating site should pass an individual DIS compliance test, like the DIS Test Suite.[3] Once the individual compliance tests are complete, then sites can join the rest of the network on a one-by-one basis to begin interoperability testing with the other sites.

The time spent upfront thoroughly testing individual sites more than pays for itself in the long run. It is much easier to troubleshoot a problem when only one site is involved as opposed to having multiple sites. Also, unexpected PDU data can affect different sites in different ways, making it even more difficult to find the cause of the problem. Individual compliance testing is also a more efficient use of resources. If multiple sites are interconnected and a problem occurs, then personnel at each site must spend time troubleshooting a problem that could have been discovered locally. In addition, simulation resources are wasted when bad data is passed over the network. At a minimum, network interface units must weed out the bad data before passing it along to the local simulation devices. At the worst, non-DIS-compliant data can cause simulations to crash, thus eliminating any training opportunity for the operator of that simulation device.

There are other DIS issues besides being able to support specific PDU types. One of these is update rates. The DIS standard states the default amount of time between transmission of a simulation entity's position is five seconds, unless the dead reckoning tolerance has been exceeded.[4] Often, sites violate this update rate by sending updates at different rates, based on local requirements. Some sites update at a slower rate in order to reduce the amount of traffic on their local area network, but this can cause problems at other sites that are expecting the standard rate. For instance, if the update rates are too slow, other sites will assume the entity no longer exists and will remove it from the list of active entities and all visual displays. Then, when the update does arrive, the site must insert it into the active list again, and the entity will suddenly reappear on the visual displays. This causes entities to pop in and out of the visual displays, resulting in an unrealistic training environment.

Another example of a DIS-related problem that should be checked during testing is the implementation of the Start and Stop PDUs. Many sites implement these PDUs so that all entities on the network are frozen or unfrozen. This is fine on a local area network, but when connected to a wide area network, each site's Start/Stop PDUs should only affect that site's entities. During one exercise, our F-16 cockpits kept unexpectedly coming off freeze and crashing, and we had to keep reinitializing them. This was due to another site which sent out improperly addressed Start PDUs. Problems like this should be caught during testing to avoid wasting valuable training time during the exercise.

Thorough testing is also required to identify and correct fidelity mismatches and incorrect entity identifications. For example, during testing for MDT2, we found that one site was scoring 500- and 2,000-pound bombs as mortar shells. We also discovered that the location of a major road differed by as much as 300 meters between different simulator databases. Without extensive testing, neither of these problems would have been caught before training began.

It is also important to test using the expected amount of network traffic as early as possible. Unfortunately, testing is rarely possible using all the simulation systems in a realistic manner. The primary reason for this is that the warriors who will use these simulators are typically not available until the exercise actually starts.

Such testing, however, is critical for ADS exercises with large numbers of entities. Individual sites may have problems processing the large numbers of entities on the network, and, if the expected network load is not present early enough during the testing period, there may not be enough time to correct the problems. This happened to us during the STOW-E exercise. During testing, we typically only saw 100-200 entities on the network, and we never saw more than 800 entities at one time during the test period. Then, during the exercise, there were 1,700 entities present, and several of our systems choked under the increased processing load. Our plan-view display could not update fast enough, and eventually it crashed, leaving us "blind" as far as seeing the scenario. The network interface units for the F-16 simulators also had a difficult time processing the increased amount of data. One result of these processing problems was that the entities in the pilot's out-the-window display appeared to jump instead of smoothly move within the virtual scene. We may have been able to fix these problems prior to the exercise if we had been able to detect them during testing.

Once DIS compatibility and interoperability requirements are satisfied, the system configuration should be baselined, and no software changes should be made until after the exercise is completed. New problems can arise or old problems that were once fixed can suddenly reappear after a programmer makes one seemingly innocent little change to the software.

Exercise Control

A lack of appropriate control over unfolding events during the execution of the exercise is another reason why distributed simulation has failed to achieve its full training potential. The distributed nature of ADS exercises allows the creation of complex, synthetic environments that offer more realism than previously available; however, having participants scattered geographically also makes it very difficult to orchestrate events in a way to maximize the training benefits.

Of course, it is impossible to have any control over an exercise if there is no means for the exercise director to communicate with the participating sites.

Exercise directors should use a telephone conference call among all participating sites to convey information during execution of the exercise. Currently, the reliability of telephone conference calls is much higher than the reliability of sending digital voice data over the network, and the importance of exercise control necessitates using the most reliable method of communication available. AL/HRA recently participated in an exercise that relied solely on digital voice communication for all voice traffic, and when we lost communication due to compatibility problems with our digital voice unit, we had no way to let the exercise director know that our pilots would not be able to talk with the weapons controller. Flying the mission was a waste of the pilots' and controllers' time, yet we couldn't convey that information to the exercise director.

Even when a reliable communication link is used, sites can still miss important information. It is difficult for each site to have someone constantly monitor the exercise control network--sometimes personnel must walk away to reset a computer or possibly answer another phone. During these gaps, if the exercise director announces, for instance, that the network will be down for an hour, not all sites may get the information. These sites may have pilots in the cockpit waiting for an expected mission to begin. To avoid this type of situation where trainees are potentially wasting their time, exercise directors should use a roll call when announcing information that is of importance to all sites. By going through the list of participants one by one, the exercise director can ensure that everyone is listening and gets the word.

The exercise director should also use the control network to closely monitor execution of the scenario. During the confusion of large-scale exercises, it is easy to forget about individual sites, but in order to maximize the training potential, the exercise director must know whether the scenario is unfolding according to plan. For example, AL/HRA participated in an exercise where our F-16 pilots were to fly as part of a strike package. Enroute to the target, we realized we had no escort and that none was forthcoming. We later learned that the originating site of our escorts had network problems and was not able to carry out its mission. If the exercise director had been aware of this and had let us know, perhaps we could have delayed the mission or at least exercised command and control procedures to inform the flight of the status of the escorts. This would have offered the opportunity for some useful training. As it was, everyone associated with this mission missed a valuable training opportunity and the F-16 pilots flew a meaningless mission.

Recommendations

In order to maximize the training benefit of advanced distributed simulation exercises, we recommend program managers follow these guidelines:

1. First and most important, develop a list of comprehensive training objectives.

2. From the training objectives, derive the scenario, communication plan (data and voice), and list of potential participating sites.

3. Define exercise management requirements, to include security, exercise control, mission initialization, and after action reviews.

4. Review site capabilities and ensure that assigned missions are within the capabilities of that site's simulators.

5. Finalize scenario, simulation data requirements, communication requirements, and the exercise schedule.

6. Develop a comprehensive testing plan.

7. Conduct rigorous testing, and then establish a baseline for the system.

8. Pretrain and rehearse participants.

9. Conduct the exercise.

10. Archive exercise baseline, exercise data, and document lessons learned.

Conclusion

Based on our observations, we believe that ADS has the potential to significantly enhance combat mission training. However, in order to fully realize this potential, exercise planners and trainers must work together to define the training requirements. Once the training audience and training objectives have been defined, the appropriate simulation technologies and training strategies should be identified. Failure to adequately define training requirements, identify simulation resources and training strategies, and test system components leads to the fog-of-simulation in which resources are ineffectively used and trainees become the fodder for technology demonstrations.

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